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GUGGENHEIM AERONAUTICAL LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

FATIGUE STRENGTH OF METAL SANDWICH
TYPE CONSTRUCTION.

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FATIGUE STRENGTH OF METAL SANDWICH TYPE CONSTRUCTION

Thesis by

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SUMMARY

An investigation was conducted to determine the fatigue strength of a new type of all-metal sandwich panel structure, designed and furnished by Western Engineering Associates of Los Angeles. This structure consisted basically of a new type of embossed core attached by spot welding to one or more smooth sheets of the same metal. Specimens tested were all of the single core, single skin type. Metal used was 24ST aluminum alloy of 0.032 inch thickness. This construction affords high structural rigidity for its weight. Two patterns of the embossed core were tested. One of the specimens had its core embossed with a triangular pattern, the other with a square pattern.

The specimens were tested by utilizing them as simply supported beams, loaded in the center by a sinusoidally varying load of constant maximum magnitude. This load was applied by means of loading bars, one on the top of the specimen, the other on the bottom. These bars had flat, one inch wide surfaces, contacting the specimen. To prevent the sharp edges of the bars from causing local failures of the specimens, a layer of one-eighth inch thick koroseal was used between the bars and the specimen. Specimens tested had a length between end supports of 16.7 inches. Their width was 9 inches.

The loading obtained was a combination of bending and shear. The shear stress was of such a low magnitude, however, that it could be neglected.

Failure of the specimens was deemed as occurring at the time the

first crack appeared. A method was devised for crack detection that consisted of laying down a conducting strip over a thin insulating layer in a network fashion, covering all saddle points of the core in the central area, since previous testing had disclosed the fact that failure occurred at these points first. Any crack in one of these saddles caused a break in the conducting strip which changed the bias on the controlling electronic tube to a cut off value. This tube was part of an Eccles-Jordan Trigger circuit which with associated tubes allowed current flow through a thyratron relay circuit opening the starting circuit of the testing machine, causing it to stop.

The data shows that for the specimens oriented in a normal fashion, that is, with one of the sides of the square or triangle of the core parallel to the loading bar, which was the situation for most of the tests, the square pattern is vastly superior to the triangular one, as regards fatigue strength. For specimens oriented in this way the square pattern withstood a bending moment of 13.45 inch pounds per inch of width; whereas the triangular pattern withstood only 9.28. Two tests conducted with the square core having the sides of the squares at an angle of forty-five degrees to the loading bars gave results about midway between. However, the effective EI for this configuration was considerably reduced, and consequently actual failure stress was probably about equal to that for the case where the sides were parallel to the loading bar.

The triangular pattern was actually much worse than the curve shows. At the higher loads cracks occurred with very few cycles of loading. Automatic cut-off feature was not in use for these tests. In service it is highly possible that overloads of short duration might cause small cracks which would become focal points of fatigue failure, thus reducing the fatigue strength well below the design point. This weakness of the triangular pattern arises from the fact that smooth fillets or saddles, joining depressed and elevated portions of the core, are harder to obtain in this pattern than in the square one. Wrinkles and tool marks were present in almost every one of the triangular specimens tested.

LIST OF ILLUSTRATIONS

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INTRODUCTION

Tests were conducted to obtain data concerning the fatigue strength of a special type sandwich construction, composed of one sheet of embossed aluminum alloy spot-welded to a flat sheet of the same material. Figure 1 shows the material as tested. Previous static tests were conducted in GALCIT Structures Laboratory to determine critical column, bending, shear and other properties of the material. The results of these tests are compiled in Reference 1.

Fatigue tests were made with a constant load type of machine, namely the Universal Fatigue Testing Machine SF-1-U in the Structures Laboratory of GALCIT.

EQUIPMENT AND PROCEDURE

The specimen dimensions were nine inches in width with a span between supports of 16.7 inches. Two types of sandwich construction were tested. One had an embossed core of a square pattern, the other had a triangular pattern. Only one combination of thicknesses was tested. This was one in which both skin and core were of 24ST aluminum alloy 0.032 inches in thickness. Overall maximum thicknesses of the two specimens were 0.391 inches for the triangular and 0.357 inches for the square. For appearance of the square pattern ready for the test see Figure 1.

All specimens were prepared for testing in the following manner: Two thin coats of Radio Service Cement were sprayed onto the top surface of the core. Coverage was confined to a path of about one inch width leading from near the end of the specimen, down its edge to the center, thence across, covering all of the saddle points in the central area, returning along the opposite edge to a point near the end support. Next, wire terminals were cemented onto the extremities of the cement coverage. Paper was utilized to eliminate contact of the wire with the metal. Finally, a continuous filament of graphite was painted onto the specimen, commencing at one terminal following the insulating cement, and ending at the opposite terminal. Saddle points were crossed parallel to their ridges. The filament width was approximately one-eighth inch, narrowing to a fraction of that in the region of the saddle points. The resistance of this circuit averaged approximately 100,000 ohms. The material used for the graphite filament was a product having the trade name Aquadag. Appearance of the square core specimen ready for testing was as shown in Figure 1.

The testing machine used was of the constant maximum load type. Its designation was Universal Fatigue Testing Machine SF-1-U. This machine obtained its load by means of an eccentric rotating mass that was constrained from moving in the horizontal direction. Rotation speed was constant at 1800 R.P.M., thus specimen was subjected to a sinusoidally varying load of constant maximum magnitude throughout the test. The machine was modified by having placed in series with the starting button, a two way switch. When this switch was open the machine could not be started. In parallel with this switch was a relay, which itself was part of the electronic control circuit. Thus when the relay was closed the starting circuit of the testing machine motor was closed and machine could be started by pressing the starting button. However, when the relay opened,the starting circuit was broken and the machine stopped. For testing with electronic control, the two way switch was left open and starting circuit completed through the relay. See Figure 4.

The load was applied to the specimens by means of two loading bars. One bar, on the bottom of the specimen applied the up load, the other on the top of the specimen applied the down load. These bars were one inch square steel, twelve and one-fourth inches long. To prevent local buckling failure of the specimens from the sharp edges of the bars, koroseal sheet one-eighth inch thick was placed between the bars and the specimen. End supports for the specimens were one-half inch diameter steel rods, that were secured to the stationary part of the testing machine. The specimen's end was squeezed between two of these rods to prevent up or down motion, but to allow some motion along its length. Details of the loading adapter and testing machine set-up may be viewed in Figures 2, 3, and 10.

The tests were run in the following manner: The specimen was put into the loading adapter and secured. A piece of sheet aluminum was secured to the loading bars in such a manner that it projected out horizontally about a half inch from the bars and could be utilized for measuring amplitude of motion. Filament terminal wires from the specimen were connected into the grid circuit of the control tube. With the electronic control circuit energized, the reset button was pushed, causing the thyratron tube to cut off and permit the relay to close. In the event the filament was shorted the relay would not close. Load setting was then made by changing the eccentricity of the rotating mass. The machine was then started by pressing its starting button and adjusting the rheostat control to the full speed position. The cycle counter was previously set to the zero position. The amplitude of oscillation was measured utilizing the aforementioned projection of aluminum sheet. The machine was run until such time as the specimen developed a crack across the filament, at which time shut-down occurred.

RESULTS AND DISCUSSION

The data obtained is compiled in Tables I and II, and displayed graphically in Figures 5, 6, and 7. Failure for this test was designated as the appearance of a crack across the filament. Several tests were run in which cracks appeared in saddles not covered with the filament. The results of these tests were thrown out.

In general, it was determined that the square pattern was vastly superior to the triangular one in fatigue strength. This superiority is immediately evident in Figure 5, where curves for the two specimens are plotted. However, when the loading of the square pattern was at an angle of forty-five degrees to the sides of the squares its effective EI per inch of width was reduced and the fatigue strength was correspondingly reduced. Only two specimens were tested in this fashion. The results of these two tests show that with this orientation the fatigue strength of the square core lies about half-way between that for normal orientation and that for the triangular core. This test leads to the consideration that for a given thickness of core and skin there is some optimum size of core stamping that gives the most desirable combination of stiffness and fatigue strength, inasmuch as EI per inch is a function of the number of saddles or size of stamping.

In an attempt to correlate or compare results with those obtained for a uniform beam, a calculation was made using the standard engineering formula for the stress due to bending, assuming that the neutral axis of the specimens tested was at the exact center of the specimen. On this basis, fatigue failure of the square plate occurred at a loading greater than 10,000 psi. Fatigue strength of 24ST is generally given as in the vicinity of 14,000 psi, which would indicate that the square pattern, at least, had relatively good properties as regards fatigue; especially so, considering the depth of stamping of the core.

Figures 6 and 7 give a comparison between the deflection as measured in the testing machine and that that would be obtained using values of EI as outlined in Reference 1 for the same static load. The difference can be attributed to (1) non-uniformity of specimens and (2) variation from line load in center. The loading member was one inch wide and had the same width, one-eighth inch thick sheet koroseal cemented to the faces contacting the specimen. This width of loading member caused the specimen to be restrained somewhat in the center.

Difficulty was experienced in making up the specimens. The graphite, which was colloidal in nature, would contact the metal through the porous portions of the cement insulation. It was found that if a resistance meter was utilized at the time the graphite was applied, the operation was simplified. One lead of the meter was connected to the terminal of the filament from which the painting was to start. The other lead was grounded to the plate itself. Thus, when a porous part of the insulation was painted over, deviation from infinite resistance could be immediately noted and filament detoured around this point, or the defect remedied by spraying another layer of cement in that area.

Figures 8 and 9 indicate the effectiveness of the crack detection. Figure 8 shows a crack across a saddle point with the graphite fracture ensuing. Figure 9 shows one of these cracks with the graphite and cement removed. Many machine stoppages occurred with the crack causing the shut-down so fine as to be barely visible at a magnification of 40 times. It was necessary in almost all cases to utilize a resistance meter to determine in which saddle the crack occurred before the failure could be found.

One stoppage occurred when the filament cracked across a tool mark. The filament was repaired, only to have the specimen develop a crack at this point and again shut down the machine.

CONCLUSIONS AND RECOMMENDATIONS

The square pattern was found to be decidedly superior to the triangular one with respect to fatigue strength. The triangular pattern, if stamped in such a manner that smoothness over the fillets or saddles could be attained, might have a fatigue strength commensurate to that of the square pattern. Failure of the triangular specimens was aggravated by tool marks and wrinkling of the metal in the fillets. Material of this type, if placed in service, would be apt to fail with an overload condition lasting for a very few cycles. At higher loads, cracks in the triangular specimens occurred almost simultaneously with load application. Data for higher loads was obtained watching a resistance meter and shutting the machine down manually when effective resistance of the specimens became approximately double their original value. In the case of the triangular specimens, at high loads, the machine was scarcely brought up to speed before the resistance meter began to show evidence of a crack.

It is recommended that the tests be continued on this material to determine the optimum pattern size for various thicknesses of sheet. This could be done by testing a given core-skin thickness combination in varying core pattern size. It was planned to test one other pattern size for this investigation, but similar thicknesses of specimens could not be obtained.

APPENDIX

CRACK DETECTION METHOD

The development of this method came as a result of the fact that the specimens tested would have to crack completely across the core before the limit stop circuit of the testing machine would operate. It was felt that plates should be considered failed long before this point was reached. In most cases pieces of the core metal were broken off before limit stops were touched.

The method of using fine wire cemented down over the critical points was considered but discarded as being not too feasible because of the contour of the core and the number of critical points to be covered. The method of using a graphite filament over an insulating layer appeared to be the easiest method and was tried. Using a brush to apply the insulation was early discarded, inasmuch as brush marks would leave small spots where the graphite could contact the metal. It was found that when the graphite was applied prior to the time the cement was completely dry a certain amount of shorting out could be discerned on the resistance meter. This was especially true in application of the graphite to the paper used to hold the wire to the terminals. It was found desirable to allow the specimen to dry for about eight hours after spraying before commencing application of the graphite. As was pointed out, securing one lead of the resistance meter to the terminal at which painting of the graphite was to be commenced and the other to the plate itself eliminated the chance of having a ground in the filament. The resistance meter could be watched during the painting of the filament. Any time the graphite was painted over a porous portion of the insulation a sizable deflection of the resistance meter occurred. It was a simple matter to wipe off the shorted-out portion of the filament with a damp paper towel. This could be done with the graphite wet or dry. It is interesting to note that a completed circuit immediately after painting would have a resistance in the neighborhood of two million ohms. This value would decrease to approximately one hundred thousand ohms upon drying.

The filament could withstand considerable strain. It was tested on an aluminum tensile specimen at loads up to 60,000 psi without failing. It has a decided strain gage property but appears to be somewhat unstable and subject to fair-sized resistance changes with changes of temperature and humidity.

The electronic circuit was designed especially for these tests. It was equipped with a power circuit designed to give a constant voltage output. Use was made of an Eccles Jordan Trigger circuit in the first stage of control. The remainder of the circuit was designed so that once the thyratron tube fired the relay would remain open until such time as the reset button was pushed. The circuit was foolproof for the tests conducted. No false shutdowns occurred. Besides this, the circuit would not permit the relay to close if the specimen to be tested had a shorted filament.

REFERENCES

1. "The Strength Properties of a New Type Sandwich Panel," California Institute of Technology Final Report on Contract No. NOa(s)8976, 6 April 1949.

TABLE I

Square Pattern .032 x .032 24ST Sheet

Overall Max Thickness 0.357"

Dimensions 16.7" x 9.0" $EI = 2560$ lb.in^2

D Pattern Ref. 1

Load Pounds	Amplitude of Vibration Inches	Cycles to Break
60	0.51	83,200
55	0.42	76,000
50	0.45	87,000
45	0.32	106,000
47	0.33	145,000
42	0.34	155,000
38	0.30	178,000
35	0.225	318,000
32	0.235	117,000
30	0.230	1.974×10^6
28	0.225	7×10^6 No Fail
26	0.235	7×10^6 No Fail

Loading at 45° to sides of core pattern

30	0.30	212,000
35	0.37	96,000

TABLE II

Triangular Pattern .032 x .032 24ST Sheet

Overall Max Thickness .391"

Dimensions 16.7" x 9.0" EI = 2110 and 2480 lb.in.^{2} core up
core down

B Pattern Ref. 1

Load Pounds	Amplitude of Vibration Inches	Cycles to Break
58	0.47	13,000
50	-	6,000
45	0.36	24,000
42	0.33	38,000
37	0.34	30,000
35	0.255	72,000
30	0.21	235,000
28	0.19	161,000
26	0.18	102,000
24	0.195	304,000
22	0.16	131,000
18	0.138	2.5×10^6 No Fail

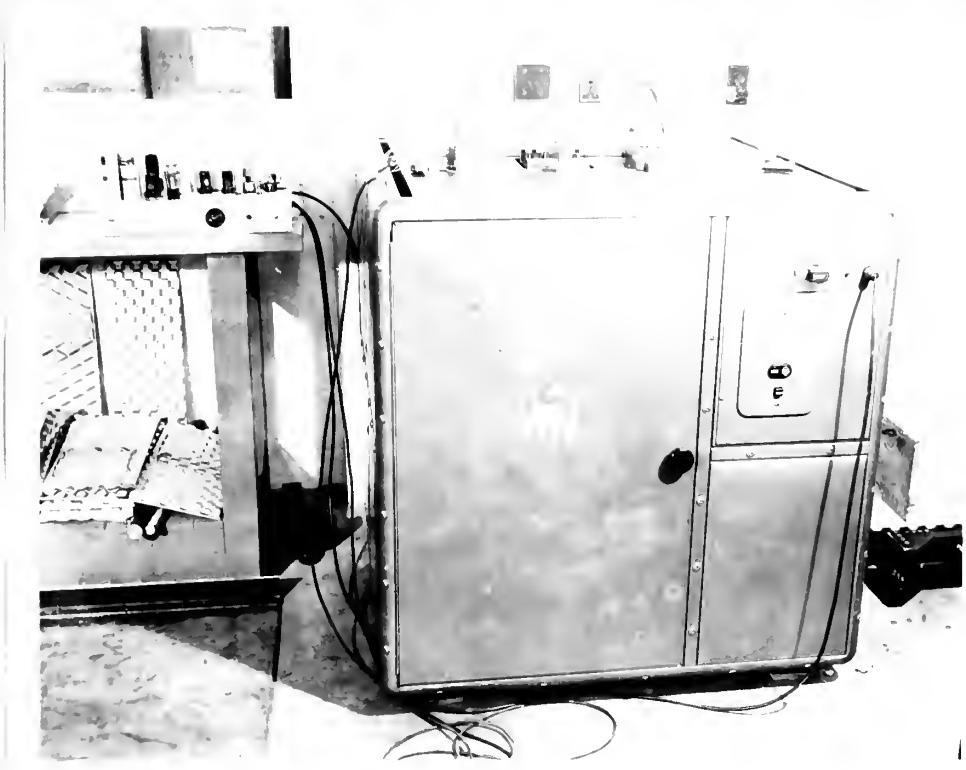


Figure 1

Photograph of Test Specimen with Crack Detecting Filament

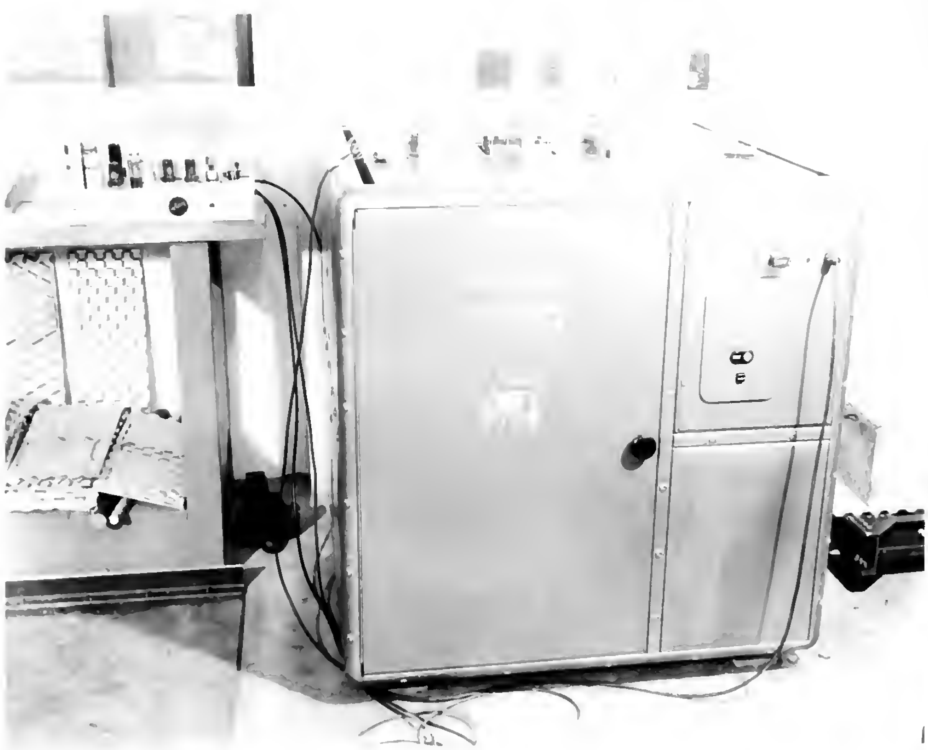


Figure 2

Testing Machine with Electronic Cut-off Circuit

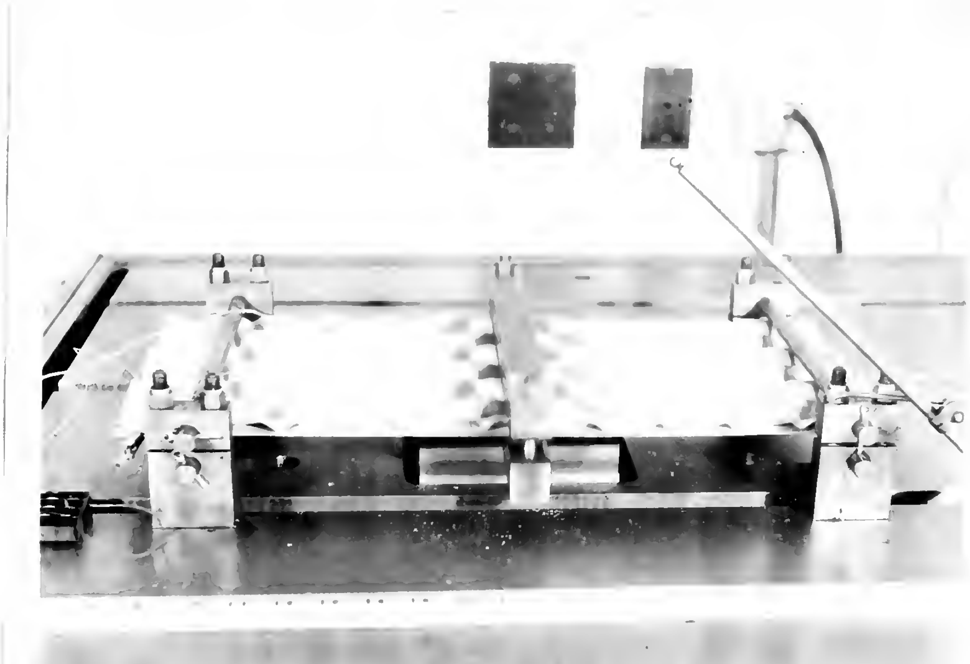
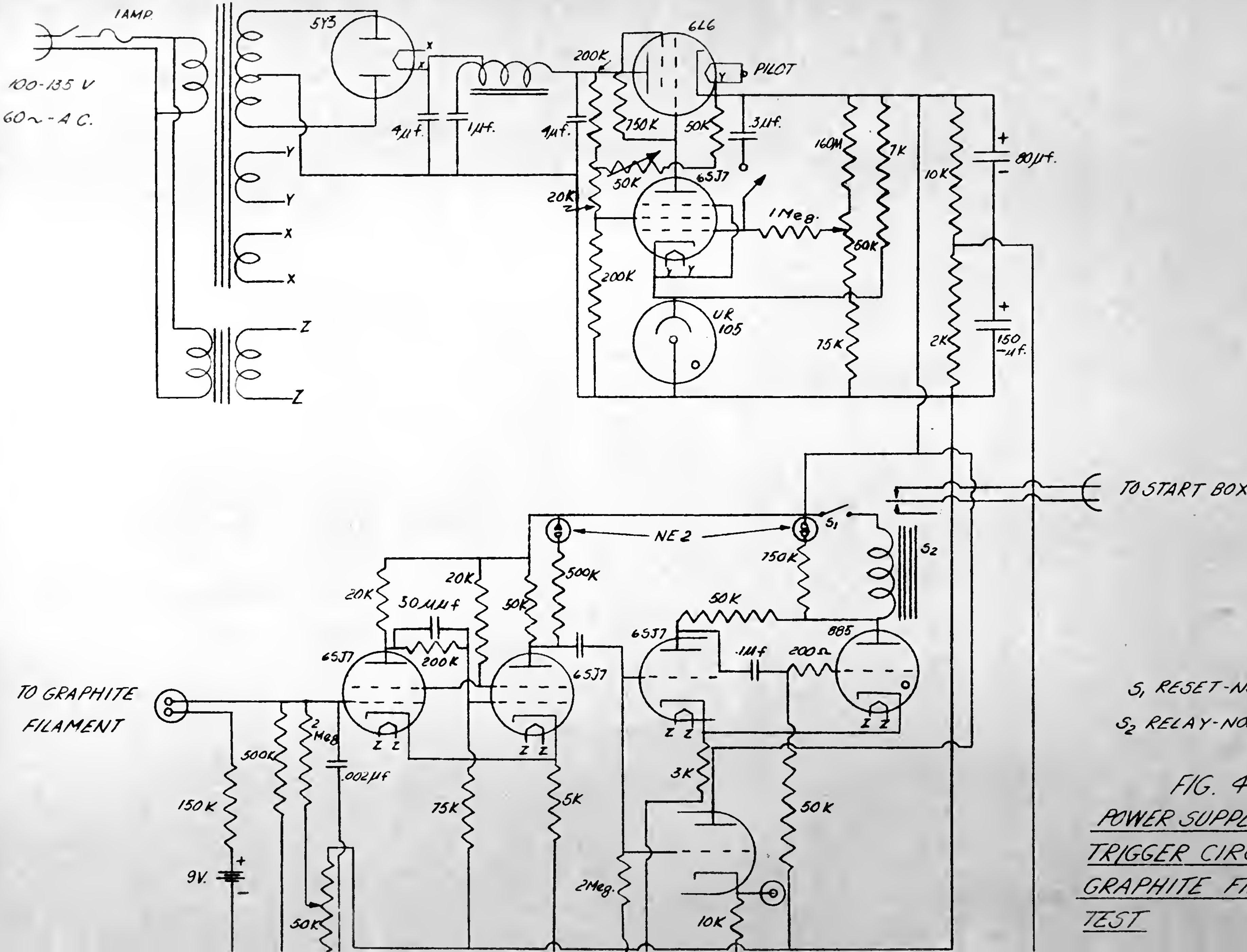


Figure 3

Close-up of Specimen Being Tested

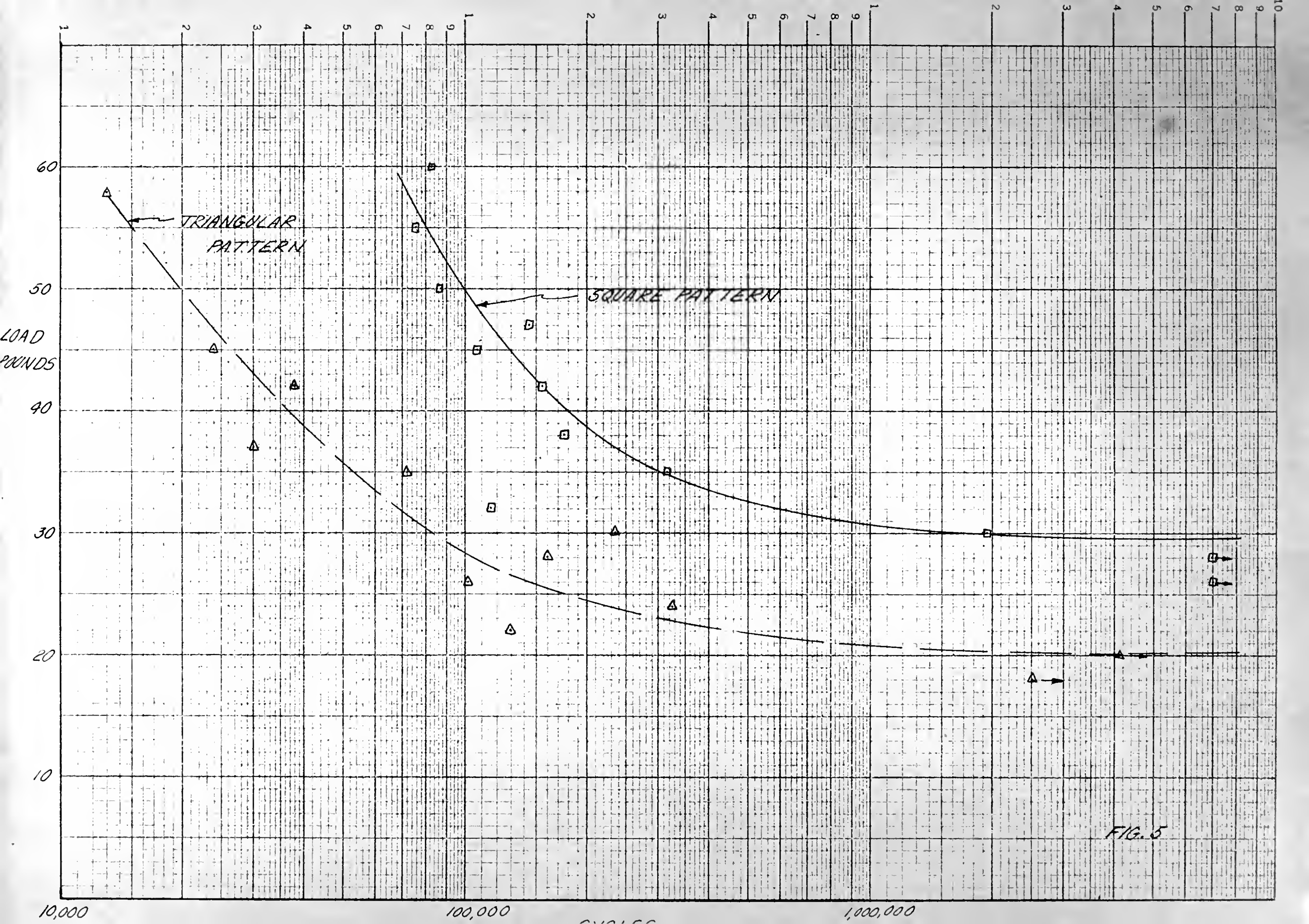


S1 RESET-NORM. CLOSED

S2 RELAY-NORM. CLOSED

FIG. 4

POWER SUPPLY AND TRIGGER CIRCUIT FOR GRAPHITE FILAMENT TEST



TRIANGULAR PATTERN
SQUARE PATTERN
LOAD POUNDS
60
50
40
30
20
10
10,000
100,000
1,000,000

FIG. 5

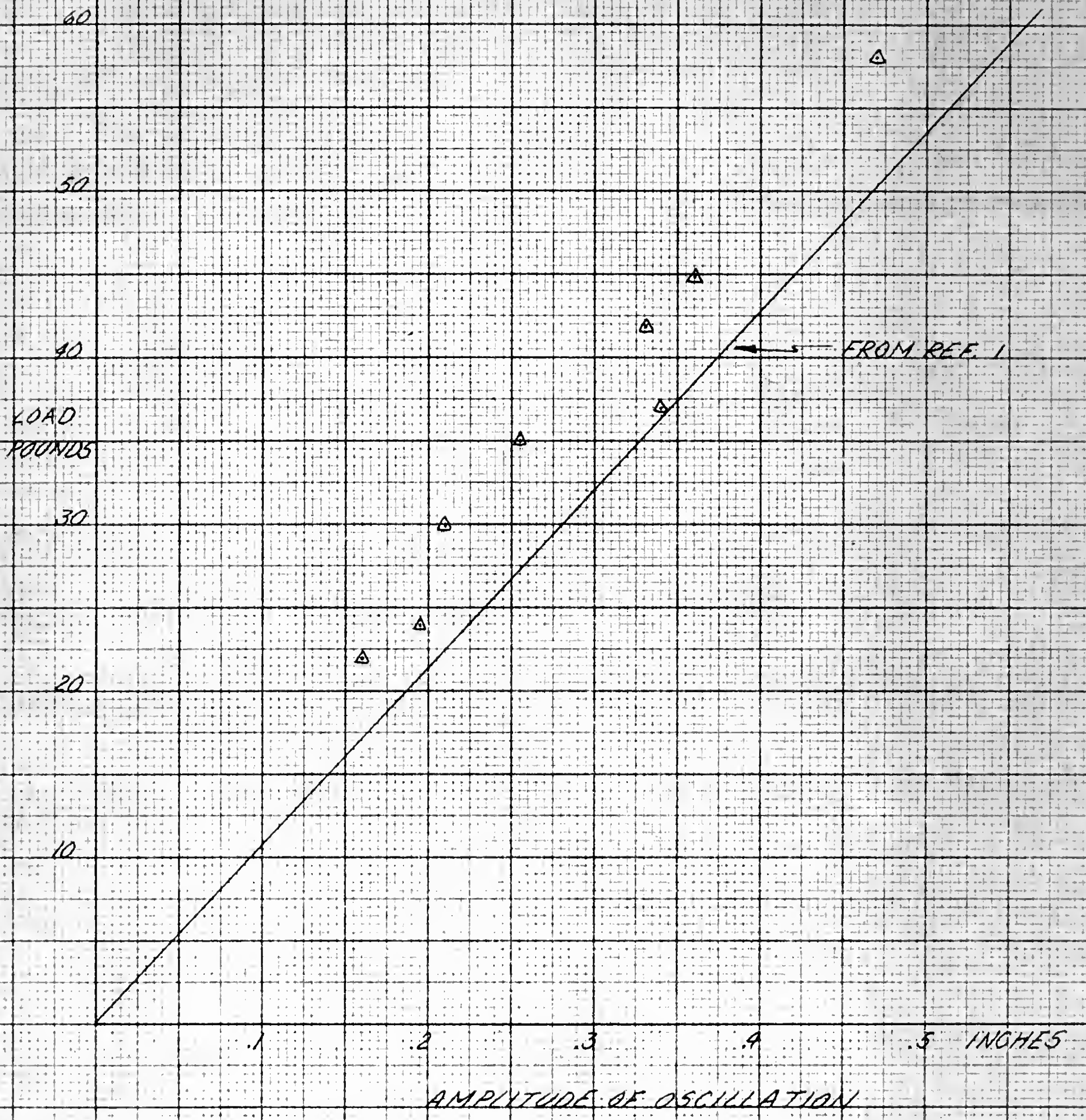


FIG. 6

COMPARISON OF AMPLITUDE OF OSCILLATION
WITH STATIC AMPLITUDE COMPUTED USING
EI OF REF 1

TRIANGULAR PATTERN

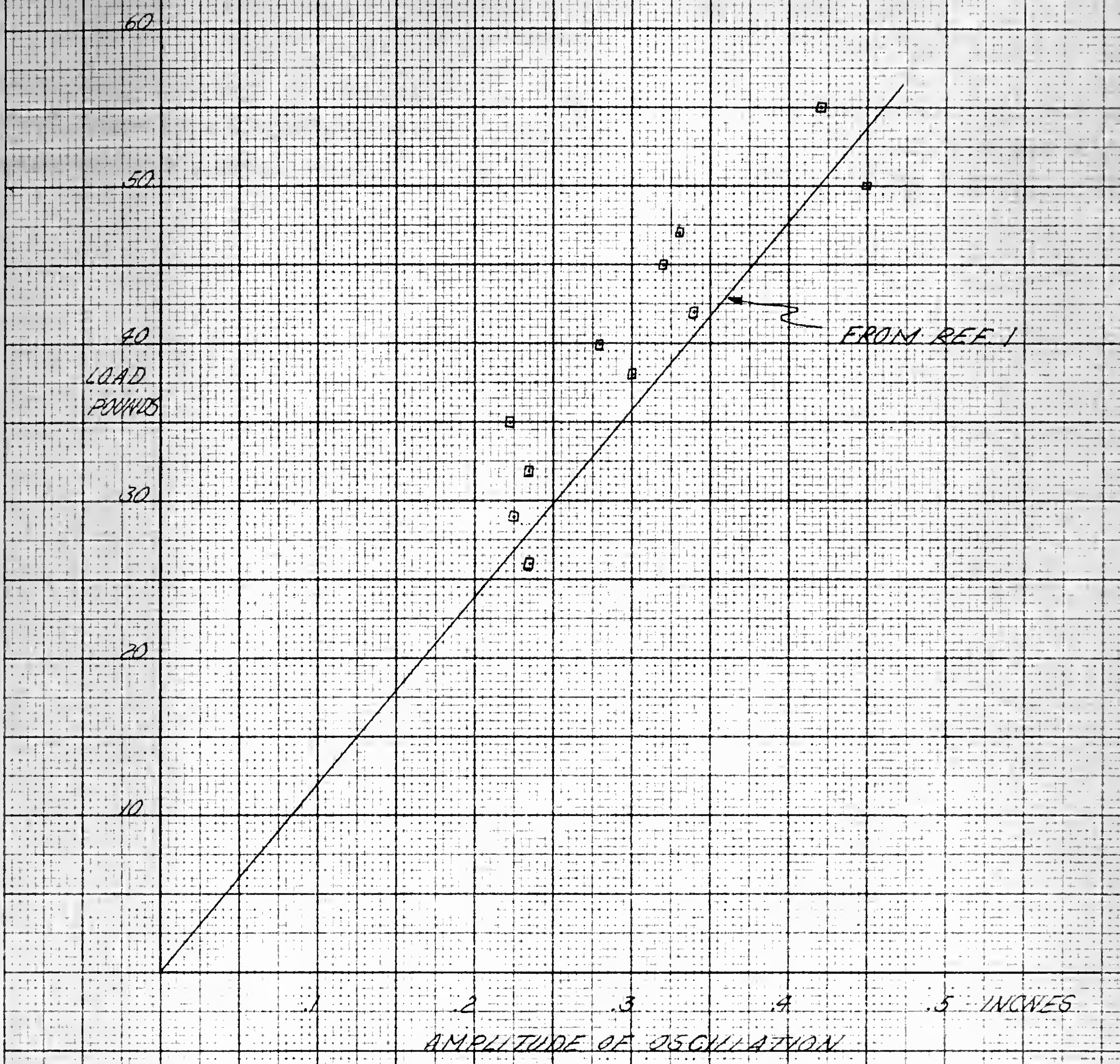


FIG. 7
COMPARISON OF AMPLITUDE OF OSCILLATION WITH STATIC AMPLITUDE COMPUTED USING EI OF REF. I
SQUARE PATTERN

Figure 8

Photomicrograph of Crack Across Filament - Magnification 50 x

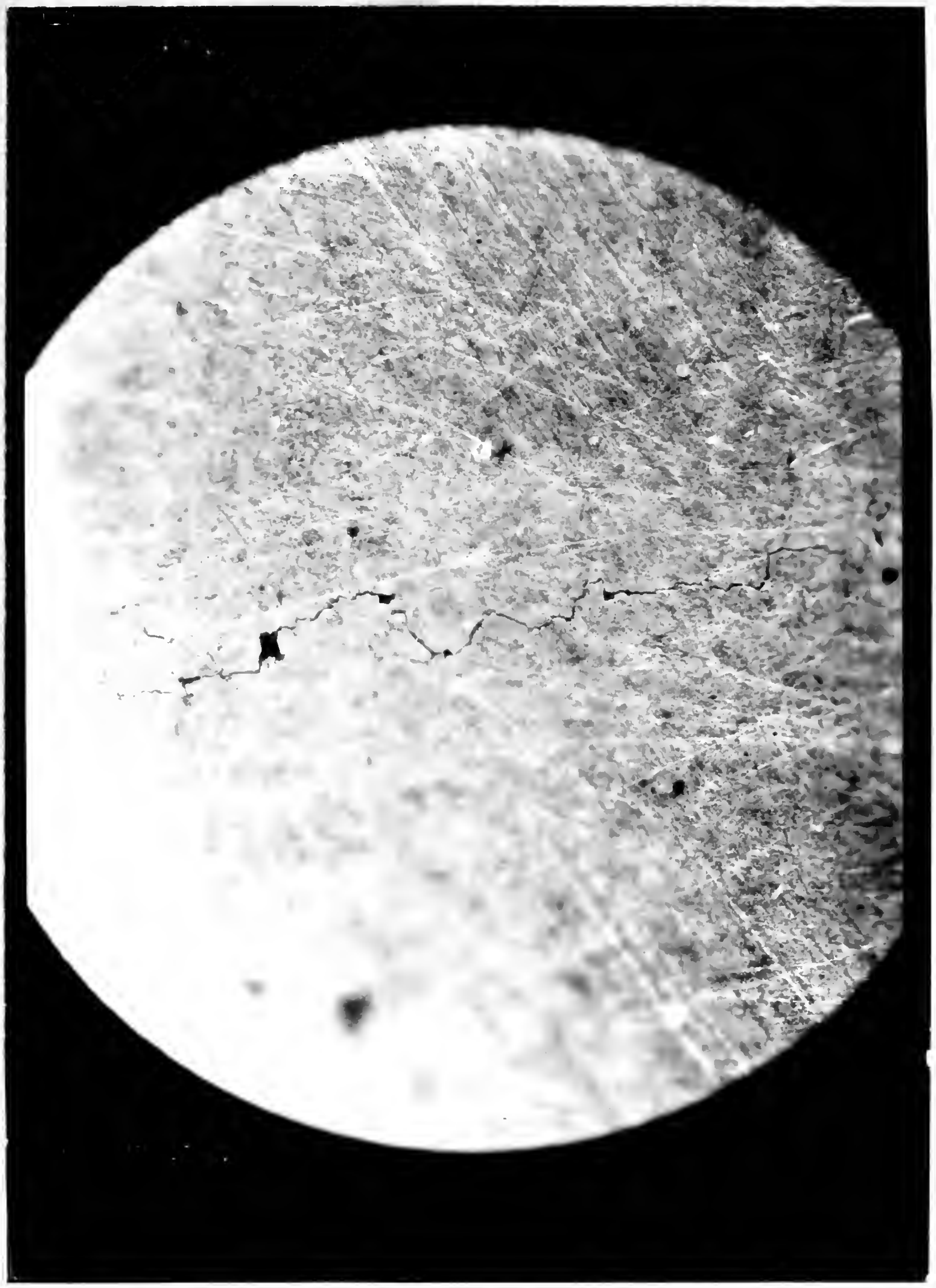
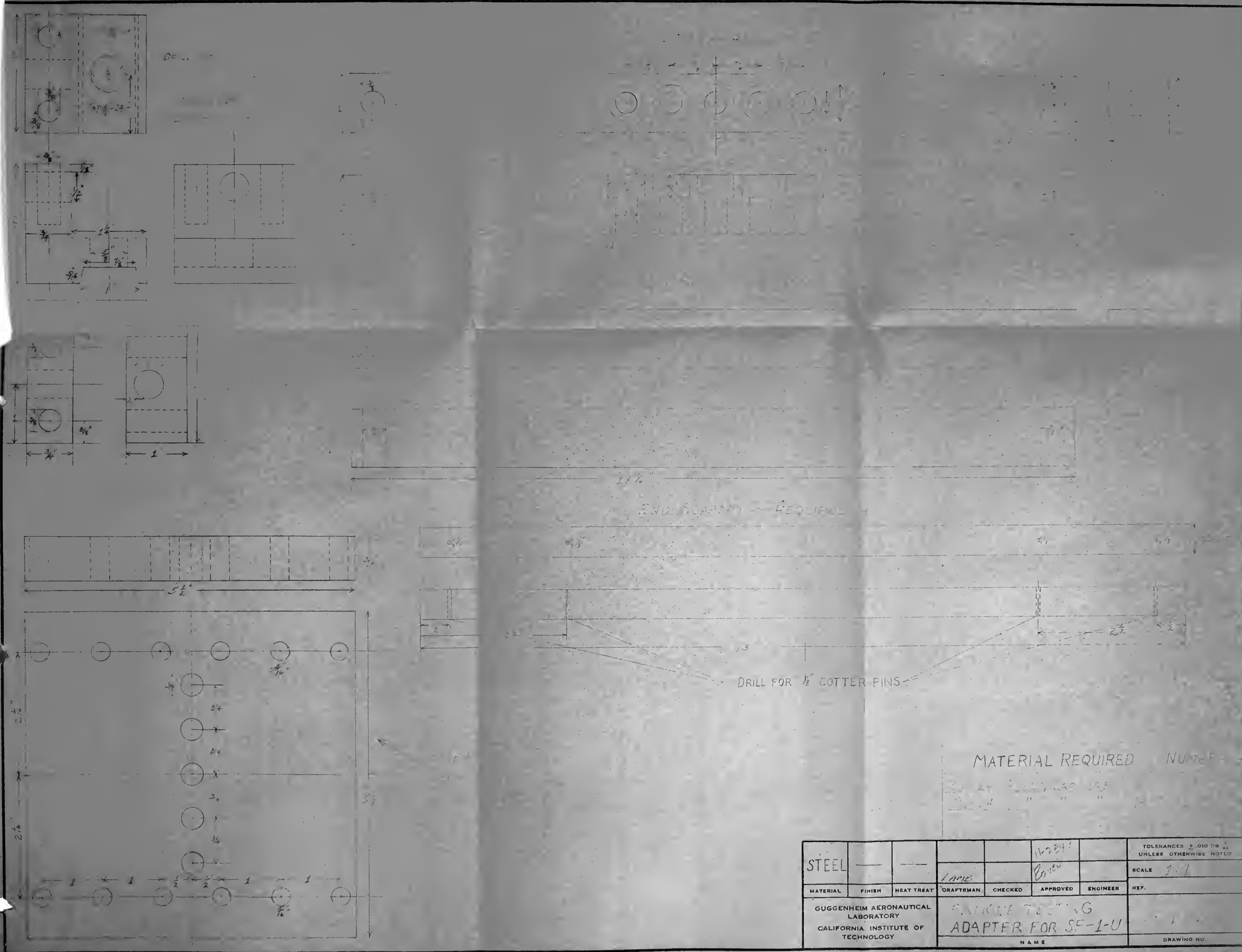


Figure 9

Photomicrograph of Crack with Filament and Cement Removed

Magnification 50 x


DRILL FOR 1/8" COTTER PINS
MATERIAL REQUIRED
STEEL
MATERIAL
FINISH
HEAT TREAT
CRAFTSMAN
CHECKED
APPROVED
ENGINEER
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
ADAPTER FOR SF-1-U
NAME
TOLERANCES ± .010 OR ± 1/64 UNLESS OTHERWISE NOTED
SCALE
REF.
DRAWING NO.

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